The deeper hidden message in Maxwell's equations

Why have Maxwell's Equations survived for so long?

by Ivor Catt

DECEMBER 1985

In November's article[1] I investigated Maxwell's Equations, generally regarded as the greatest mathematical achievement in science.*

In the 1830s, Faraday discovered electromagnetic induction, thus closing the loop between electricity and magnetism. This discovery paved the way toward the rapid growth of electricity-based industrialization and the high technology which shapes today's world.

By making the key discoveries of their era, uneducated technicians like Michael Faraday and James Watt threatened the scholastic myth, that all progress, including scientific progress, needs must use the rigour and discipline controlled and celebrated by academics in places like Cambridge University. The ultimate in scientific rigour (*rigor mortis?*) was held to be mathematics. Biography and History of Science writings spawned in academia present the thesis that, lacking mathematics, Faraday could not and did not really effect his discovery of electromagnetic induction. Rather, he stumbled into it, but it could only be properly exploited decades later, after Professor Maxwell had placed a mathematical structure upon Faraday's fumbling, unscholarly ideas. Thus, according to the Platonic interpretation of history, Professor Maxwell, not Faraday the technician, paved the way for massive exploitation of electromagnetism in transformers, motors and generators. The deeper hidden message in Maxwell's Equations is that, do what they will, the local yokels will not replace mathematical academia as the fount of knowledge and progress.

*And if mathematics is the highest flowering of science, then Maxwell's Equations become the greatest achievement in *all* science.

In a previous article[1] I posed two questions:

> Do Maxwell's Equations contain any information about the nature of electromagnetism?
>
> Why do academics and practitioners generally think that Maxwell's Equations are useful?

I am sure you will have found my answers unsatisfactory. The reason is that they were based on certain assumptions, and failed to dig deeply enough into the underlying motivation, psychoses and myopia within contemporary science.

The underlying battle for the soul of science is between the practical engineer on the one hand and the Platonic pure mathematician on the other.[2] For his part, the mathematician sees this battle as more important than search after truth or technology-fuelled search after new sources of wealth. For him, the important thing is Form; the purity and beauty of his world, and his ability to control and manipulate it intellectually. (The profane aspect of this idea is the desire to impose a structure onto any 'discipline' such that it is easy to teach and, more importantly, easy to set exam questions on). One FRS told me that physical reality was composed of sine waves, and this encapsulates the mathematician's attitude to our world.

A good example of an academic with the mathematician's attitude is Sir James Jeans. He was highly regarded in the 1930s both as a Cambridge academic and as a populist, much like Sir Fred Hoyle in the 1950s. In his book "The Mysterious Universe",[3] Jeans gives a clear view of the attitude of the Platonic mathematician discussed in the last paragraph.

> "By 'pure mathematics' is meant those departments of mathematics which are creations of pure thought, of reason operating solely within her own sphere, as contrasted with 'applied mathematics' which reasons about the external world, after first taking some supposed property of the external world as its raw material"

On the next page, Jeans goes on to write,

> " . . . the universe appears to have been designed by a pure mathematician."

The important thing is not to ponder over the possible contradiction between these two statements, but to grasp the mentality underlying them. This mentality, usually in a better camou..flaged and less grotesque form, is what made possible the survival of mathematical absurdities like Max-

well's Equations for such a long time.

Jeans then goes on helpfully to point out the flaw in his argument:

> "This [last] statement can hardly hope to escape challenge on the ground that we are merely moulding nature to our preconceived ideas. The musician, it will be said, may be so engrossed in music that he would contrive to interpret every piece of mechanism as a musical instrument; the habit of thinking of all intervals as musical intervals may be so ingrained in him that if he fell downstairs and bumped on stairs numbered 1, 5, 8 and 13 he would see music in his fall. In the same way, a cubist painter can see nothing but cubes in the indescribable richness of nature – and the unreality of his pictures shews how far he is from understanding nature; his cubist spectacles are mere blinkers which prevent his seeing more than a minute fraction of the great world around him. So, it may be suggested, the mathematician only sees nature through the mathematical blinkers he has fashioned for himself. We may be reminded that Kant, discussing the various modes of perception by which the human mind apprehends nature, concluded that it is specially prone to see nature through mathematical spectacles. Just as a man wearing blue spectacles would see only a blue world, so Kant thought that, with our mental bias, we tend to see only a mathematical world. Does our argument merely exemplify this old pitfall, if such it is?
>
> "A moment's reflection will shew that this can hardly be the whole story. The new mathematical interpretation of nature cannot all be in our spectacles – in our subjective way of regarding the external world – since *if it were we should have seen it long ago* [my italics]. The human mind was the same in quality and mode of action a century ago as now; the recent great change in scientific outlook has resulted from a vast advance in scientific knowledge and ot from any change in the human mind; we have found something new and hitherto unknown in the objective universe outside ourselves. Our remote ancestors tried to interpret nature in terms of anthropomorphic concepts of their own creation and failed. The efforts of our nearer ancestors to interpret nature on engineering lines proved equally inadequate. Nature refused to accommodate herself to either of these man-made moulds. On the other hand, our efforts to interpret nature in terms of the concepts of pure mathematics have, so far, proved brilliantly successful. It would now seem beyond dispute that in some way nature is more closely allied to the concepts of pure mathematics than to those of biology or of engineering, and even if the mathematical interpretation is only a third man-made mould, it at least fits objective nature incomparably better than the two previously tried."

C.A.M.

Professor Einstein argued similarly in 1949[4]:

> "... the approach to a more profound knowledge of the basic principles of physics is tied up with the most intricate of mathematical methods."*

I have put the weak point in Jeans' argument above in italics. The mathematicization of science developed with a vengeance as a result of the professionalization of education. Dr Ivor Grattan-Guinness once pointed out to me that the decline, or ossification, of science into 'maturity' was a necessary result of the introduction of universal education in the mid-19th century, because it caused the growth of a powerful group with a vested interest in knowledge, the professional teachers.

Basil Bernstein[5] says that a body of knowledge is property, with its own market value and trading arrangements, to be protected by the social group which administers that body of knowledge.

If only those who lived off a body of knowledge could make that knwledge more secure, their careers and pensions would be protected. Two strategems were open to them[6,7,8]:

- to freeze the knowledge base so that it would not be a prey to the ebbs and flows of the real world, and
- to develop the thesis that any change in, or extension of, the knowledge base could only be properly effected by the professional 'knowledge magicians', 'knowledge doctors' or 'knowledge brokers', with their special, skilled, occult ways of pushing forward the boundaries of knowledge.'

It would of course be less effective for the professional group of knowledge brokers merely to bless or condemn influxes of new knowledge. (Admittedly they *do* do that. All my attempts to publish work on electromagnetic theory and on computer architecture (US patents 3913072 and 4333161) were blocked for more than ten years by learned journal referees, who are by definition knowledge brokers). The knowledge brokers' power would be greater if they required that new knowledge arise in their own prescribed style, preferably devised by one of their members, a knowledge professional. An early example of this in my own publications is that under threat of firing by my boss, who was also a Fellow of the IEEE, I was compelled[9] to include a ghastly, recondite, mathematical last section, written by someone else, in my 1967 IEEE paper[10].

*In passing, it is worth noting from page 62 of the same book, where Einstein writes: "The special theory of relativity owes its origin to Maxwell's equations of the electromagnetic field." In the literature we repeatedly come across assertions that Maxwell's Equations play a pivotal role in science.

We have reached the following point in the argument. Under cover of claiming to maintain standards of scholarship, or to maintain rigour, knowledge brokers (1) block the ingress of new knowledge, particuarly revolutionary knowledge in the Kuhnian sense[11], and also (2) they make a last-ditch, bitter defence of old, discredited knowledge, like Maxwell's Equations.

> "Unfortunately, however, when the body of knowledge is bigger and the rate of inflow of new knowledge is smaller, more and more of the activity within the knowledge [base] becomes 'celebration', more and more ceremonial rather than exercise in depth. As a result, a different calibre of person is attracted to that large knowledge, lacking the ability to understand and defend a body of knowledge with many levels of meaning. They are 'maintenance men' rather than 'builders'. The central body of knowledge ossifies, becomes brittle and then disintegrates."[6]

We need to realise that the cardinals who suppressed Galileo did not need to be competent theologians or scientists; they only needed a much narrower competence, the ability to distinguish between the orthodox and the heretical, in both content and in style[12]. As to style, it is worth pointing out that possibily the ability to publish radically new, revolutionary[11] knowledge in the old accepted style would prove that after all the new knowledge was not truly revolutionary. So arguments about style, which are regularly lodged against my writing, including my last article,[1] create a beautiful Catch 22 situation where no new knowledge can be published.

In this penultimate paragraph I mention in passing The Lateral Arabesque, 'Arabesque' having the meaning ascribed to it by Dr Peter[13] rather than its dictionary meaning. In the engineering sense, the supposed situation where academia controlling a discipline – electromagnetic theory for example – maps onto the real subject, is

unstable. If at any moment the professors administering a discipline happen to be weak in one branch of it, they will tend not to examine their students in it, and so will tend to select out those up and coming students who have that sub-discipline as their strength. Positive feedback down the generations of students will further the retreat from that particular sub-discipline. (Sir James Jeans and Einstein could be said to be telling us very wordily that academia have selected out budding scientists who showed a grasp of the physics, rather than the maths, of their subject.) Similarly, the whole of academia will move deeper and deeper into any misconception or aberration, and there is no corrective force. In my view, 'The Lateral Arabesque' makes it possible for an academic subject's content to end up with no overlap *at all* onto the real subject from whence that branch of academia sprang. I have just completed four years as Principal Lecturer in a College of Further Education, where I was struck by the lack of any significant link between the Higher TEC syllabuses that I taught and the real subject, electronic design, in which I had been earning my living in industry for the previous 20 years. As a minor example, academia evolved the myth that dissatisfaction among logic designers with the indeterminate state of an R-S bistable if driven on both its inputs at the same time led to the development of the J-K bistable; then that the instability of the J-K led to the development of the Master-Slave J-K, regarded in academia as the Rolls-Royce of bistables. A nice idea, but with no historical foundation.

A larger example would be academia's fixation on Quine-McCluskey, something not even heard of, let alone used, by engineers in the real world of logic design. Although I was in the best position possible to introduce or alter syllabuses, being on the County Committee, during my four years as a P.L. I failed to change one word of one syllabus. I struggled very hard to do so.

To sum up. Professionalization of knowledge leads to a vested interest in knowledge,

which leads to the disintegration of competence among the knowledge professionals as well as the prevention of the ingress of new knowledge. Something like this syndrome is needed to explain the survival of Maxwell's Equations for so long.

Moving graphics help to illustrate the subtleties of electromagnetic theory. For information on the availability of videotapes, please write to Ivor Catt, 15 King Harry Lane, St Albans AL3 4AS.

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A mathematical rake's progress

Ivor Catt looks back on how he nearly became a maths addict

JANUARY 1986

In my article of last November, I showed that Maxwell's Equations, so long thought to contain the heart and essence of electro magnetism, told us virtually nothing about the subject. Then, in my December article, I discussed the academic mafia's vested interest in knowledge (see panel). Here I try to discover who this group of charlatans*, the maths pushers, are. How does a young student grow up to become part of the social group who live by mathematical nonsense like Maxwell's Equations, and who conspire to prevent the development of a scientific subject in a proper, physical way?

*The Shorter Oxford English Dictionary entry for this word is particularly apt:

> **Charlatan** 1. A mountebank who descants volubly in the street; esp. an itinerant vendor of drugs, etc. . . .
> 2. An empiric who pretends to wonderful knowledge or secrets . . ., a quack.

However, if we then look up the entry for Empiric, the whole picture backfires on us.

Concern about this question led me to look back on my own education. What pressures were exerted on me to become a mathematical rake?

My experience indicates that the slide is similar to that of the drug addict — a number of small, apparently innocuous, slips downward, culminating in total separation from reality. As we progress through school and college, we are fed a series of potions, each more heady than the last.

The process started with the calculus. My introduction to it, at the age of 15, was worrying and disorienting. It was part of the great disaster which I thought had overtaken me in my first few months in the sixth form. Whereas I had always been good at maths, I found the first few months in the sixth form confusing. Even though Sam Richardson was a very good teacher, and I had help from my mother, a brilliant mathematician, at home, I couldn't understand the basis of what we were learning in mathematics, particularly the calculus.

This was a new experience for me. Previously, I had always found maths easy, and scored high marks. Now, suddenly, it was different. This was serious because if I tried to retreat from maths into some other field, all nearby subjects were based on maths anyway. There seemed to be no escape from my new-found inadequacy in mathematics. As the first half-year exams approached I became more and more worried, because still I couldn't grasp the basis of what I was being taught.

The flaw in the calculus package is what I now recognise as the reductionist fallacy a misconception which underlies and undermines western philosophy.* The error is to think that 'the whole is the sum of the parts', no more; that lots of bits of string are quite as useful as (and the same thing as) a long piece of string. Putting it another way, the problem of discontinuities was ignored. I was right to worry.

A whole array of misleading, damaging concepts slipped in with i, or j as we electrical engineers call it. "Two for the price of one"; if a+jb = c+jd, then a=c and b=d; so we can do two jobs at once. Pretty, but a delusion, similar to the illusion that we can drive better after drinking, and for the same reason — our vision is blurred.

*Titus, H.H., Living Issues in Philosophy. American Book Company, 1964, pp.148, 527, 540 etc.

Hot on the tail of j came that awful array of cons under the appropriate descriptor 'sine'. I shall not develop this theme fully, but only repeat that one FRS went so far as to say that "Physical reality is composed of sine waves". In fact, the sinusoidal wave, which is a camouflaged circle, is Ptolemy's pure, circular epicycles fighting back against Kepler's less pure, more real, ellipse. Kepler, who himself loved the idea of the 'harmony of the spheres', saw a more pure 'equal areas in equal time' rather than a distinctly un-heavenly, earthy, (we would say 'real',) ellipse.

The *Wireless World* July 1981 editorial, 'The decline of the philosophical spirit', contrasts the nineteenth century, when scientists were interested in and capable of distinguishing between the physically real and the mere mathematical construct, and today, when scientists no longer know or care about the difference, and have even developed a philosophy of science which confuses them.*

An example of the destructive effect of sine is the way in which it suddenly appears, unannounced and without justification, on the second page of a text book discussion of the t.em. wave.

In the event, my first half-year exams in the sixth form didn't seem too hard, and I felt that I must have scored over 50%,

*Popper, K. Conjectures and Refutations, R.K.P., 1963, p.100

which would give me a breathing space in which to re-plan my future. To my astonishment, I learned that I had scored 99% and 92%.

However much I might *think* I didn't understand what was going on in maths, the marks I scored 'proved' otherwise. My high scores told me that I *was* still good at maths, as I had always been. However, a nagging suspicion remained with me that something was amiss. I doubted whether I could really have misjudged the situation so badly. Today, I believe that I was correctly judging the situation, and it was my exam marks that were wrong. I was being brainwashed into the belief that understanding was unnecessary, even impossible; that success meant the ability to manipulate the symbolism of the subject, not to understand it. I was being encouraged, the initial carrot being high exam marks, to turn the handle of the mathematical barrel organ, and not to ask too many awkward questions.

I seemed to learn my lesson, and later on, when taking A-levels, I gained a State Scholarship in maths although only 17 years old. This was a remarkable achievement, and should have secured my loyalty to the administrators of the mathematical myth. However, I was already questioning the usefulness of some of this maths, particularly the interminable geometry (since dropped) in the Cambridge Open exam, and so at Cambridge I decided to leave my strong subject, maths, and read engineering.* My background must have made me particularly sceptical. My mother had scooped the lot, gaining the top 'first' in maths in London University, but the payoff to her in benefits in later years proved minimal.

The next piece of blatant brainwashing occurred during my engineering course in Cambridge. We had a lot of thermodynamics, which was very mathematical. One day I asked my tutor, Professor Binnie, what practical interpretation I could place upon an equation containing a college of terms involving the three e's — energy, enthalpy and entropy. His answer was that I should not bother to look for a physical interpretation, but should merely regard it as a piece of algebra to be manipulated according to the rules of algebra. I was shocked by this, and I remain shocked today. Had I left maths and taken up engineering for nothing?

Whereas drawing, or draughting, was strong in the Cambridge Engineering Faculty and seemed to occupy a large part of our time, being the only subject you were not allowed to fail, electricity was weak, rating only one lecture a week, or at

*I love the Heaviside remark; "Whether good mathematicians, when they die, go to Cambridge, I do not know." — Heaviside, O., Electromagnetic Theory, Vol. 3, Dover, 1950. (First published 1903.)

most two. One suspects that conservative Cambridge of the 1950s hoped that this newfangled electricity thing would prove to be a flash in the pan, and go away soon. (Gaslight, I have been told, was very pleasant; much softer on the eye than electric light.) I suspect that my later success in elecromagnetic theory resulted from the lack of teaching in it that I had sustained while at college.

We did not cover the Laplace Transform, and this set me apart from upstart graduates from redbrick universities, who enjoyed discovering how backward Cambridge was. I was lucky in this omission, because I now feel that transforming is one of the destructive mathematical techniques in engineering that increases the divorce from reality, and which is the legacy to engineers from mathematicians. Whereas to me it is obvious from first principles that to get constant current through a capacitor* you need a continually increasing voltage, I recently found that for a student of Laplace this is the conclusion of a lengthy piece of complex calculation.

Thus was the stage set for Maxwell's Equations, that phoney apology for electromagnetic theory, which held sway for a century and so befogged the subject.

There is a similarity between the maths pushers and drug pushers. Both entice the victim with promises of Elysium. Both gradually increase the dose. In both cases, there is nothing at the end of the rainbow.

* using theory N

Mathematical mafia

The twisting of historical fact in the hands of the academic mafia is beautifully illustrated by the case of the discovery of the electromagentic theory of light. Obviously, a mathematician would like us to believe that the proposal that light was electromagnetic in nature resulted from subtle manipulations of his electromagentic equations by Professor Maxwell the mathematician. In fact, Whittaker[1] says that the proposal that light is electromagnetic came from Faraday in 1851, when Maxwell was 20. Now it might be asserted that the vague suggestion by Faraday was confirmed and strengthened by Maxwell's mathematics. However, Chalmers[2] says that there is an error in Maxwell's calculations, which "led Pierre Duhem to accuse Maxwell of adjusting his calculation so that he could arrive at a theory of light which he [or should we say Faraday?] already had in mind."

The truth appears to be that the idea preceded the maths; the maths was force-fitted onto the idea, like the ugly sister's shoe; and then the mafia claimed the maths generated the idea. The prince was not hoodwinked, and neither should we be. This racket, of forcing mathematical liturgy onto a reluctant discipline, constantly recurs in science, perhaps reaching its most grotesque in so-called 'computer science' courses.

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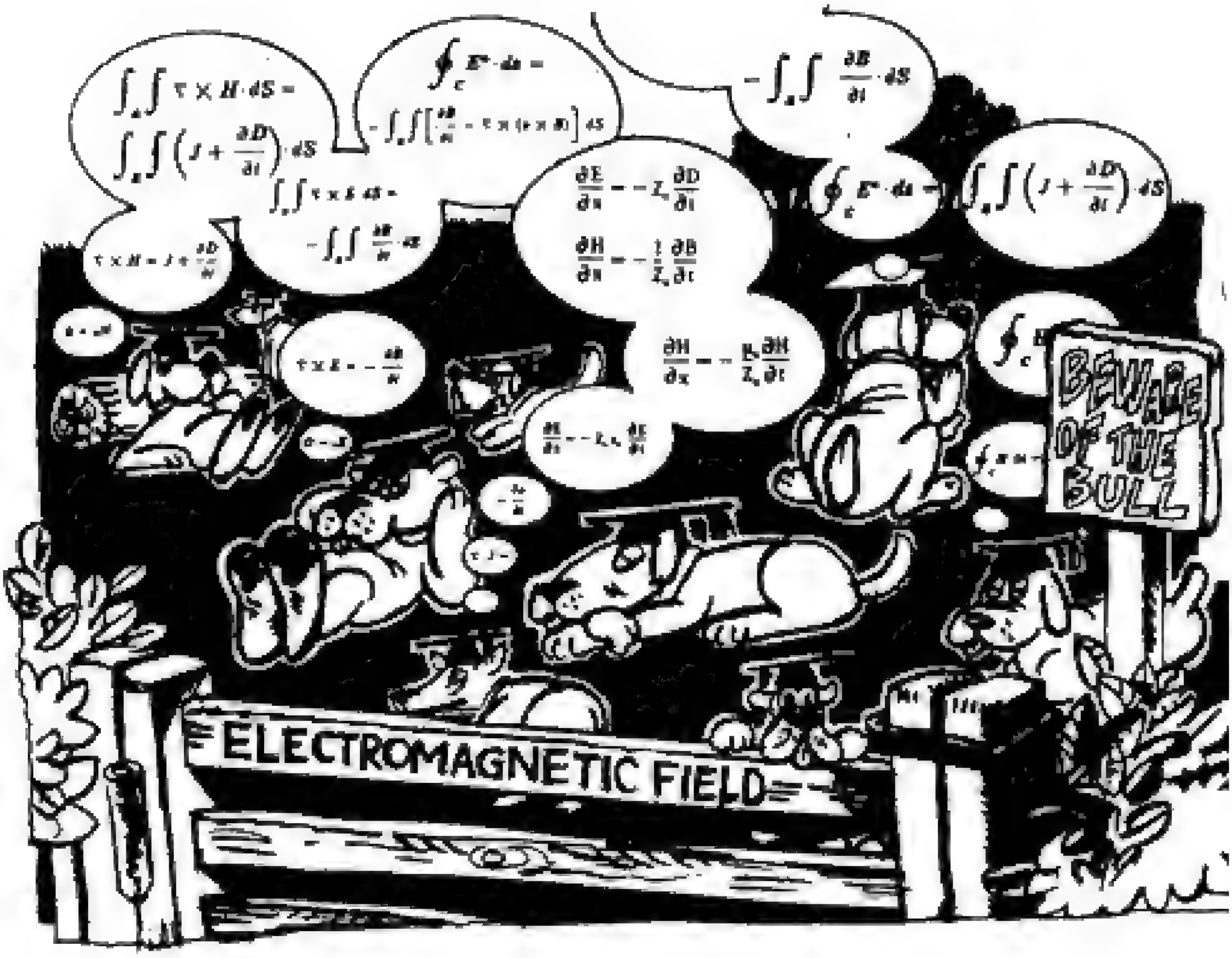

C.A.E.

ENERGY TRANSFER

In a realistic physics all interaction should be treated as a discrete cause-effect process, which is intuitively self-evident from the principles of physical reasoning but it is not realised in present day theorising. Such a discrete process generates a power series as the interaction propagator passes to-and-fro and standard analytical techniques can be used to determine whether the series will converge to a finite limit or not. (The information accumulated in the series coefficients corresponds to the field exchange particles of high energy physics.)

If it tends to an asymptototic equilibrium the power series may be replaced by a more compact function from which the power series can be regenerated. The reversible correspondence between power series and generating function representing it is only valid within the radius of convergence for the iterative process of the cause-effect interaction.

This is the crucial problem for advance in theoretical physics: to develop a non-equilibrium behaviour with mathematically self-consistent formulae using continuous variables. Self consistency means that we *assume* that an equilibrium can exist between the variables (such as in a circuit) then proceed to calculate their would-be values.

For instance; Newtons laws of mechanics and gravitation and Einstein's relativistic modification of them, and de Broglie's 'wave' description for electrons in atoms, the formulae of electromagnetic theory and electronic circuit design. These all correspond to asymptotic equilibrium of a discrete interaction: the conditions of interaction under which these self consistent limiting descriptions are valid (as a calculation short-cut to a solution that exists is never even thought about.

The example I can quote is of feedback in a control system which I derived longhand in *WW* Dec. 1983. A finite time delay was supposed in a feedback control system and its response to the simplest possible stimulus of a unit step was described using discrete element analysis.

The 'operational amplifier' formula was rederived including valid limits for convergence, which is essential to understand the negative-feedback instability (so intuitively obvious) and why it is not predicted by the self-consistent op-amp formula. The self consistently derived op-amp formula is beautifully simple but wrong in principle, since the solution cannot exist (meaning well defined finitely stable behaviour) outside the region of convergence.

(As a matter of interest the Nyquist formula is just a special instance of the Curie-Weiss susceptibility law for a loose — coupled system and fits into a wider scheme of 'phase transition' formulae which includes the relativistic formulae for the limiting speed of light to material motion.)

C.A.M.

Upon similar reasoning concerning what mathematical representations mean, the formulae of relativity and general relativity are calculation short-cuts. In all probability Einstein got the right answers for the wrong reasons. The de Broglie wave formula for equilibrium behaviour of electrons in atoms is a piece of brilliant insight but falls into the same classification of self consistency. A more fundamental mechanics is needed if we are to unify physics.

The Catt anomaly is based upon a misconception about the mathematical formulation of electromagentism; classical electromagnetism and its quantum, relativistic modifications can only be valid as a description for asymptotic equilibrium.

The response of any system (transmission line of interacting particles) to the transient of a step stimulus is a non-equilibrium phenomenon. hence the 'anomaly' vanishes as meaningless when it is recognised as an attempt to apply an equilibrium theory to a non-equilibrium situation. What is needed is a more general non-equilibrium theory from which to derive the equilibrium one as a special case.

E and M displacement current are not confused, as Mr Catt suggests (Letters, April). They refer to two separate aspects of an interaction, the asymptotic regime and the initial transient effects respectively where at the ultimate discrete scale of reality the mathematical sophistication of Fourier analysis is beautiful but useless.

Most worrying of all is the thought that the mathematical formulation of our physical laws (using continuous variables and compacted into generally applicable differential equations) implicity precludes certain phenomena from our reasoning which anyone with an ounce of physical insight would see as intuitively obvious though perhaps no so easy to quantify.

Algebra is just a noise-free information processing system (or medium) and logical manipulations do not add anything that is essentially 'new' beyond that physical insight which was encoded into the original formulation of the theory. As with any computing language if you put rubbish in you will get rubbish out; however, one needs to overcome the psychological barrier of the brazenly sophisticated formulae so spuriously created if we are to challenge the conclusions of the theory with *physical* reasoning to attempt unification.

One needs to discuss mathematics in everyday language to truly understand what a formula (usually in a commutative or asymptotic cause-effect logic) represents and not to float adrift in a sea of assumedly understood.

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ENERGY TRANSFER

The reversed polarity of the Hall effect, referred to by R. Petzeratt in the November issue, is not confirmed to p-type semiconductors. The same phenomenon is found in certain metals, such as zinc and cadmium. The mater was a major anomaly until the late 1920s, when it was accounted for in quantum mechnics.

As regards Catt's views concerning electrical conductivity, he seems to have confused my reference (in the February issue) to electrons entering and leaving the conduction band (from and to the valence band) with the metal strips or "bands" ins triplines. This suggeests lack of appreciation of the physical realities, except for the out-dated "cannonball" electron from classical electromagnetism, that participate in the physical processeds in conduction, such as photons and psi waves. My main point was, and remains, that the velocity of electrons does not form a strong enough foundation from which to make such pronouncements as "the death of electric current" and "electric charge does not exist" (December 1980).

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WHAT'S IN A THEORY?

Our Ivor Catt always makes cheerful light reading, especially when he points out the obviousness of some physical statements which are usually mentioned only with bated breath. Typically, in *E & WW* for November 1985 he reminded us that only ***uniquely electromagnetic*** information contained in the two Maxwell equations relating E and H in vacuum lies in the theoretical artefacts μ_0, ε_0; from them one can extrapolate to derive "the impedance of free space" as $Z_0 = \sqrt{\mu_0/\varepsilon_0}$ and "the universal velocity of light" as $C = 1/\sqrt{\mu_0\varepsilon_0}$.

The phenomenon is by no means confined to electromagnetic theory. Some of your readers might care to try the following unconventional derivation in the wave theory of matter:—

> A completely general expression for 3-dimensional waves in any linear, continuous medium is provided by
>
> $$\nabla^2\psi + \left(\frac{2\pi x}{u}\right)^2.\psi = 0. \quad ...(1)$$
>
> where ψ (psi) is "whatever it is that oscillates" in the waves and u,x are the wave velocity and frequency respectively. The last are classed as "unobservables" by the theory, so we will simply eliminate them by means of the wave axiom (self-evident truth) $u = m\nu$, obtaining
>
> $$\nabla^2\psi + \left(\frac{2\pi}{\lambda}\right)^2.\psi = 0. \quad ...(2)$$
>
> Next, on the apparent evidence of experiment we assume these matter-waves obey the momentum precept $p = mv = h/\lambda$, so that
>
> $$\nabla^2\psi + \left(\frac{2\pi}{h}\right)^2 p^2.\psi = 0. \quad ...(3)$$
>
> Now the momentum $p = mv$ is

directly related to the particle's kinetic energy $K = \frac{1}{2}mv^2$ by the form $p^2 = 2mK$; substitution for p^2 leads inexorably to

$$\nabla^2\psi + \frac{8\pi^2 m}{h^2}K.\psi = 0. \quad ...(4)$$

Finally, since the total dynamic energy of any particle is defined as $W = (K + U)$, evidently $K = (W - U)$ and therefore

$$\nabla^2\psi + \frac{8\pi^2 m}{h^2}(W - U).\psi = 0. \quad ...(5)$$

Here we have derived Schrödinger's Wave Equation, that famous, basic statement of the Wave Mechanics which students may approach only with extremest reverence. Given two further assumptions it leads to Schrödinger's mathematical model of the atom — represented as an infinite set of spherical harmonics — which is said to "explain" the atomic line spectra.

The derivation given above may be unfamiliar, but it is both simple and watertight. Step by numbered step it consists of the following physical assumptions:—

(1) let us suppose that linear matter-waves exist;
(2) Then these matter-waves must obey the wave axiom;
(3) The matter-wavelength of a particle is related in this particular way to its mechanical momentum *(de Broglie)*;
(4) The laws of Newtonian mechanics are to apply; and,
(5) A particle's energy is part kinetic, part potential.

Given at (1) the idea of matter-waves and at (2) the axiom which must follow from that, the *only reference* made to any property of the waves, namely $p = h/\lambda$, occurs at (3). The derivation is in fact complete at this point, the other two steps being added to facilitate its practical application. We note that the derivation, and therefore the wave equation itself, is invariant with respect to any definition of v, so that "any old waves will do" for the wave theory of matter. That is why a Wave Mechanician will give you an odd look if you ask him about the *frequency* of his matter-waves. Nor is any textbook willing to tell us whether these matter-waves are transverse or longitudinal. The theory doesn't know about such things, and it gets away without caring about them either!

As Mr Catt has pointed out in the case of the electro-magnetic theory, so here in the case of the wave-mechanics, and so also as is well known in the case of special relativity, the key theoretical formulations are found to rest upon two, and only two, particular and radical physical assumptions. The rest is algebra.

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Galloway

ENERGY TRANSFER

P. L. Taylor (*Wireless World*, p. 15 October 1985) likes the choice between e.m. wave energy transfer through space, as required by the Poynting vector, or through wires, as required by the Slepian vector. There is, in fact, a third choice advocated by Cambridge Professor G. H. Livens. Writing 'On the flux of energy in radiation fields' at p. 313 of his 1926 book 'The Theory of Electricity', published by Cambridge University Press, he argued in favour of an alternative to Poynting's theory. Waves do not need to carry energy at their speed of propagation. Their generation merely adds energy to a common pool of energy in the field medium at the locality of the transmitter and their absorption draws on that pool in the locality of the receiver. I like this third alternative, because it is easier for me to picture creation a a big splash in an existing smooth pool of energy than as a big bang appearing from nowhere in a complete void.

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MAXWELL

The consistence of Ivor Catt's misrepresentation of Maxwell's laws is remarkable. Whatever deficiency they do contain, if any, it is certainly not at the elementary level claimed in the issue of November 1985. ('The Hidden Message in Maxwell's Equations').

The basic problem remains apparent ignorance of vectors and the role they play in Maxwellian theory. Ivor Catt seems to think that Maxwell's laws are some kind of elaborate hoax supported by an establishment conspiracy to suppress 'alternative' theories. He also believes that equations (9) and (10) in his latest diatribe represent the views of the conspirators. If they did, he would indeed have a point. But, sad to say, the windmills that this exuberant knight errant is tilting at are significantly different from the reality of Maxwell!

The mistake he makes is fundamental and disastrous. It is entirely necessary to modern em theory that the E field vector is perpendicular to the H vector. Why, then, do equations (9) and (10) not show this? Without the direction property of a vector, em theory would fail to account for such simple phenomena as reflection. Ivor Catt attaches some mystical importance to Z_0; anyone who was properly conversant with EM theory would not. Z_0 is derived from the magnitude of the E and H vectors; their directional property is eliminated and most that is useful in the theory with it. Z_0 is not a 'primitive': it lacks directional information.

Ivor Catt's difficulties with the expression of physical concepts in mathematical form do not seem to be confined to electrical matters. True enough, if he walks along the plank far enough in the direction (hooray for direction!) 'v', 'h' does indeed decrease but so does 'x'. Sorry, Ivor old son, but you are wrong again, as you walk along the plank it is because it is going backwards underneath you that it leads to that sinking feeling.

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C.A.M.

RAKES' PROGRESS

I feel that Mr Catt (January 1986) has missed the purpose of mathematics in science. Mathematics provides a formal description of a theoretical model for empirically discovered results. Such a description is necessary for predicting other results from those already discovered.

Since the mathematical description is of a model, it cannot be expected to fit the world, warts and all. The model will deal with an idealisation; in particular, since the model is not a description of all and everything, it will entail concentrating on some effects and ignoring others. Hence the problems with defining (e.g.) ampères experimentally. Further, formulisations based on "real" numbers entail using limits which are impossible experimentally. Overcoming these problems means inventing a better model, one which includes more forces, or can be described by quantised mathematics.

The universe is quite complex, and it is often useful to deal in idealisations which ignore "irrelevant" forces. Presumably, the next round of "complete" or unified theories will bring together astrophysics, electromagnetism and subatomic physics; however, I suspect that predicting simple effects from such a theory will be very complicated.

It is for precisely the above reasons that it is wrong to attack the use of mathematics in computing science. Here, one is dealing with a situation which is wholly understood, since it has been created synthetically. One can produce complete mathematical descriptions of (e.g.) the languages in use. It is the very artificiality of the computing science world that allows this accurate formalisation, in contrast to the situation generally in physics.

ENERGY TRANSFER

Recently, since Ivor Catt first elaborated his iconoclastic views, several Wireless World readers have surfaced with their own problems relating to electric current theory. To these I would like to add my own.

At school, I was taught that the resistance of a conducting wire was inversely proportional to the cross-sectional area of the wire.

$R \alpha 1/A \alpha 1/r^2$ (where r = radius of the wire) This seemed reasonable since, just as with water running down a pipe, the thicker the wire/pipe, the more space there would be for the charge/water to pass through.

Later, I learned that electric charge only flowed along the surface of a conducting wire, (down to a certain small "skin depth"). This seemed to square with the idea that the residual charge on a conductor is to be found on the surface. However, this would lead one to imply that the resistance would be inversely proportional to the cross-sectional perimeter of the wire.

$R \alpha 1/r$

Furthermore, does a hollow conducting wire (with wall thickness greater than skin depth) have the same resistance as a solic conducting wire of the same radius?

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